# ASSIGNMENT GUIDELINE

The following points are important to remember:

1. You must complete the assignment in this MS Word document, and rename the file as:
	1. MSV 780 Fatigue (Assignment by Surname Initials).docx.
	2. Excel files shall be saved as MSV 780 Fatigue (Assignment by Surname Initials).xlsx
2. Submit the assignment and Excel file (if applicable) by e-mail to: **mheyns@investmech.com** and **paceo@investmech.com**. No faxed assignments will be evaluated. Please submit the documents in MS Word format to allow the lecturer to make changes, comments and mark it directly in the document.
3. Copy and paste all diagrams, tables, figures, etc. into this document.
4. Include proper referencing to detail according to the Harvard Method.
5. Hand sketches may be scanned/photographed and copied into the document.
6. Delivery date: see <http://investmech.com/FatigueBlog/> .
7. The following documents make part of this assignment:
	1. This document.
	2. Class notes and applicable standards.
	3. Presentations used in class.
8. Clearly articulate and motivate assumptions made, steps followed and application of theory/equations.

# STRESS-LIFE

A circular rod made of SAE 4142 (450 HB) steel is loaded axially and has a step change in diameter with dimensions . The fillet radius is ground and the surface is not exposed to a corrosive environment. Note, material parameters are available in Dowling Table 9.1.

1. Using the S-N curve estimate of Budynas, evaluate the safety factors in both stress and life if the expected service loading is 30 000 cycles at zero-to-tension force of .



Figure 1: Part geometry

# STRESS-LIFE FROM STRESS HISTORY

A double-edged-notched plate of 2024-T3 aluminium alloy with has a nominal stress versus life curve in the form , where is given by the Walker relationship:

With fitting constants: .

The plates will be repeatedly subject in engineering service to the nominal stress history shown in Figure 2. Assume that the surface is ground and is surface protected. Do the following using the Walker mean stress compensation.

1. Generate the stress spectrum (table of nominal stress and applied cycles) using Rainflow counting.
2. Estimate the number of repetitions to failure, , for 50% probability of failure.
3. Estimate the number of repetitions for a 5% probability, , of crack initiation.
4. If 200 repetitions are expected to be applied in service, what are the safety factors in life and stress for 50% probability of survival?



Figure 2: One repetition of nominal stress history on the double-edge-notched plate

# HYSTERESIS CURVE AND STRAIN-LIFE

A member made of 2024-T351 aluminium has a notch with an elastic stress concentration factor (or theoretical stress concentration factor) . One repetition of the nominal stress is shown in Figure 1 (note that the stress history has already be reordered to start at zero and have the first and last peak the peak or valley with the maximum absolute value). Please do the following:

1. Qualitatively sketch the local stress-strain response.
2. Estimate the number of repetitions, , to cause fatigue cracking using the Ramberg-Osgood stress-strain curve and:
	1. Morrow mean stress compensation
	2. Modified Morrow mean stress compensation
	3. SWT mean stress compensation
	4. Walker mean stress compensation
3. Interpret and discuss the results.
4. Which mean stress compensation rule would you suggest for this material? Why?



Figure 3: Nominal stress repetition on component

# STRESS AND STRAIN-LIFE

A shaft that supports cable pulley to lift coal from a mine was loaded in rotating bending as shown in Figure 1. The shaft was supported by bearings at its ends and was used in a hoist for lifting ore out of a mine. It was loaded in rotating bending by the forces shown and failed after 15 years of service and 2.5 × 107 rotations. An impact factor of 1.5 has already been included in the force given to roughly account for forces exceeding the dead weight of the ore, cable, and bucket. An impactor is needed dur to such effects as bouncing during loading at the bottom of the mine and acceleration to start moving the ore upward. The shaft is made of AISI 1040 steel with , and reduction in area 25%. The design drawings showed a fillet radius of 6.35 mm at the failure location, with a machined surface finish, but measurement on the shaft after failure indicated that it had a radius of only 2 mm.

1. Estimate the safety factor in stress for both the intended and actual fillet radii.
2. Does this error in manufacture explain the failure?

Design changes:

The diameter at the failure location is increased from to , with a fillet radius , having a machined surface. The shaft material is now hot-rolled and normalized SAE 1045 steel with properties: , , and 48% are reduction.

In each lift and return cycle of the hoist, the shaft rotates 108 times, and there are approximately 32 000 hoist cycles in a typical year of operation. The skip (bucket) is first loaded with coal in the mine 515 m below the pulley shaft. It then accelerates upward, next moves upward at constant speed, stops at the top of its travel and dumps the coal, and finally returns empty to the bottom of its travel. The nominal stress spectrum is given in Table 1. Combinations of nominal (without ) bending stress and numbers of stress cycles are given, where the stress cycles correspond to shaft rotations, totalling 108 cycles per hoist. The stresses assume smooth operation of the equipment; no impact factor is included. They result from the weights of shaft and attached pulleys, coal, skip, and ropes.

1. Evaluate the shaft design for resistance to fatigue failure. Is the design adequate?
2. Approximately three years after installation, the shaft failed from a large crack that had started at the fillet radius. Fifteen months prior to the failure, an accident occurred in which the skip went out of control while moving upward and crashed into the structure below the shaft, causing a nominal stress that may have been as high as 200 MPa at the instant of impact. Did the accident contribute to the failure?
3. After the failure, the shaft was replaced by a similar one made of SAE 4340 steel having . Was this a reasonable solution to the problem? What additional design changes would you suggest?

Table 2: Load spectrum of the hoist shaft for one cycle

|  |  |  |
| --- | --- | --- |
| **Loading situation** | **No. of rotations per hoist cycle** | **Nominal stress, [MPa]** |
| Accelerating | 9 | 92 |
| Up with coal | 45 | 86 |
| Down empty | 54 | 60 |
| Total: | 108 |  |
| Acceleration is ignored for the down travel of the skip. This is a conservative assumption. |



Source: (Dowling, 2013, p. 552)

Figure 4: Shaft dimensions and load case

# EVALUATION OF PAPERS

Read the following paper and answer the question(s) below:

<https://reader.elsevier.com/reader/sd/pii/S0142112314000152?token=9DC0295C61884B50E0B3F08A68E34FA87221F1A473F76E30BB1943521A78EE221A5B06FBD1CF86F31223EBD20EF42AEC>

1. Comment on the fatigue curves used in paper.
2. What multiaxial approach is best to analyse the fatigue on a 1045 carbon steel?
3. Why?

# WELD FATIGUE

## Problem Statement

A 10 mm thick circular tube with dimeter 500 mm is welded to a mounting plate of thickness 50 mm with a complete joint penetration weld that is reinforced by a 5 mm fillet weld as shown in the figure below. The weld is made from the outside only.

The circular tube is made of 350 WA structural steel with yield strength 350 MPa and ultimate tensile strength 480 MPa. The joint is surface protected and is operating at a temperature of 300 °C.

Strain gauges were used and analysed, rainflow counting carried out, from which the nominal force, , and bending moment, , (which are applied in phase with each other) resulted in the load spectrum in Table 1 over a period of 1 year.

A finite element analysis indicated that the change in radial stiffness at the joint results in a stress concentration factor of 1.2 for stress in the longitudinal direction. This is due to the fact that Poisson effects want to result in a change in the pipe diameter during loading that is restricted by the thick endplate.

Table 1: Load spectrum on a welded joint over a period of 1 year



10

500

50

x

y

z

A

B

Figure 1: Tube to endplate connection cross-section

Questions:

1. By just analysing the direction of the applied forces and moments, at which point of A or B would you expect the crack to initiate first? Please motivate your answer. **[20%]**
2. By just looking at the weld sizes applied in this joint, and by comparing the characteristic strengths for crack initiation at the weld toe in the tube and at the weld root, where do you expect the crack to initiate first? Motivate why. **[20%]**
3. What is the fatigue life of the joint for a 95% probability of survival? This is a critical joint that requires a safe life with high consequence of failure design philosophy. **[50%]**
4. What post weld treatment would you recommend to increase life, why and what increase in life will result? **[10%]**